

In-Situ Wave Observations in the High Resolution Air-Sea Interaction DRI

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LONG-TERM GOALS

Ocean wave prediction models, based on a spectral energy balance, are widely used to obtain wind-wave forecasts and hindcasts on global and regional scales (e.g., Komen et al., 1994). However, these inherently stochastic models assume a Gaussian and homogeneous sea state and thus do not describe the nonlinear instability processes that can dramatically alter the structure of wave groups and produce anomalously large waves, also known as ‘freak’ or ‘rogue’ waves (e.g., Janssen, 2003). Fully deterministic modeling capabilities are now becoming available that incorporate these nonlinear effects and provide the detailed phase-resolved sea surface predictions needed in many applications. Concurrent with the development of new models, advances in radar remote sensing techniques are enabling the detailed observation of the sea surface on the scales of wave groups and individual waves. The long-term goal of this research is to test these emerging new models and measurement technologies in realistic sea states and use them to better understand and predict the wave group structure and occurrence of extreme waves in the ocean.

OBJECTIVES

- Observe the nonlinear evolution of wave groups in realistic broad-band sea states.
- Provide ground-truth data for testing the capabilities of ship-board wave radar systems.
- Provide in-situ wave data for the verification of phase-resolving wave prediction models.

APPROACH

The primary goal of the High Resolution Air-Sea Interaction DRI is to advance observational and modeling techniques for monitoring the wave-resolved sea surface around a vessel. Field experiments will be conducted off Point Conception, California, using the floating platform FLIP with a suite of meteorological and oceanographic instruments, airborne and ship-board radar systems, and an extensive array of moored and free drifting buoys. Our proposed contribution to these experiments is a coherent array of surface-following buoys that will be embedded within the footprints of FLIP-based, airborne and ship-board remote sensing systems. The array will cover a nominal area of about 15 by 15 km that spans the anticipated evolution scales of nonlinear wave groups.

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The Datawell Directional Waverider (DWR) buoys that will be used in the experiments, are small surface-following buoys that measure vertical and horizontal water particle motion at the sea surface directly, from which time series of surface height and slopes can be extracted. The accuracy of these buoys is well established (e.g., O'Reilly et al., 1996) and their reliability in high sea states is attractive for long-term deployments in the open ocean. We have successfully used DWR buoys in the recent ONR-sponsored SHOWEX (Ardhuin et al., 2003; 2007) and NCEX (Magne et al., 2006) experiments and believe they are well suited to conduct the proposed measurements in an energetic wave environment. To accommodate both high spatial resolution and flexibility in the array design and sampling scheme, we plan to use a combination of moored and free-floating DWR buoys. The larger (0.7m diameter) DWR buoys will be moored within a few km of FLIP to obtain continuous in-situ surface wave measurements within the footprint of FLIP-mounted radar and other remote sensing systems. The smaller (0.4 m diameter) mini-DWR buoys will be deployed during the intensive phases of the experiments when ship-board radar measurements and aircraft over-flights take place. These buoys are free floating and can be deployed from the same vessel that collects the radar measurements, thus allowing for close coordination of the sampling schemes.

To optimize array design for observing wave group evolution, we will use a forward-scattering angular-spectrum model [see e.g. Dalrymple & Kirby, 1988; Janssen et al. 2006]. This model presumes waves to propagate in a half plane, thus omitting back-scattered wave energy, or waves traveling at a larger than 90 degree angle with respect to the principal direction; it accounts for cubic nonlinearity that is believed to be the primary mechanism for nonlinear wave group evolution in deep water and the associated development of freak waves (Janssen, 2003). In Figure 1 we show two simulations with the angular-spectrum model to illustrate the group-length scales and characteristics anticipated off Point Conception, California – the proposed experimental site. We initialize the model utilizing observed frequency-directional spectra extracted from the Coastal Data Information Program (CDIP) Harvest buoy located in 204 m depth off Point Conception. The initial sea surface is assumed Gaussian and homogeneous, with spectral amplitudes and phases selected from a Rayleigh and uniform distribution respectively. The model evolves these spectral components, while allowing for cubic nonlinear coupling; other nonlinear physics (e.g. atmospheric forcing and whitecapping) are not included in these simulations.

The simulations (Figure 1) include examples of typical summer and winter conditions. The summer-time example shows a long-period swell arriving from the South and a weaker high-frequency local wind sea from the North-West. The long propagation distance of the swell originating from the Southern hemisphere is evident in the narrow spectrum and long crest lengths (several km). The groups of 6-8 waves are fairly regular at intervals of about 3-4 km. In contrast, the lower panels of Figure 1 show an energetic winter storm event with strong winds and swell arriving from the North-West. This less dispersed wave field (i.e. closer to the generation source) has a broader spectrum and a more irregular group structure.

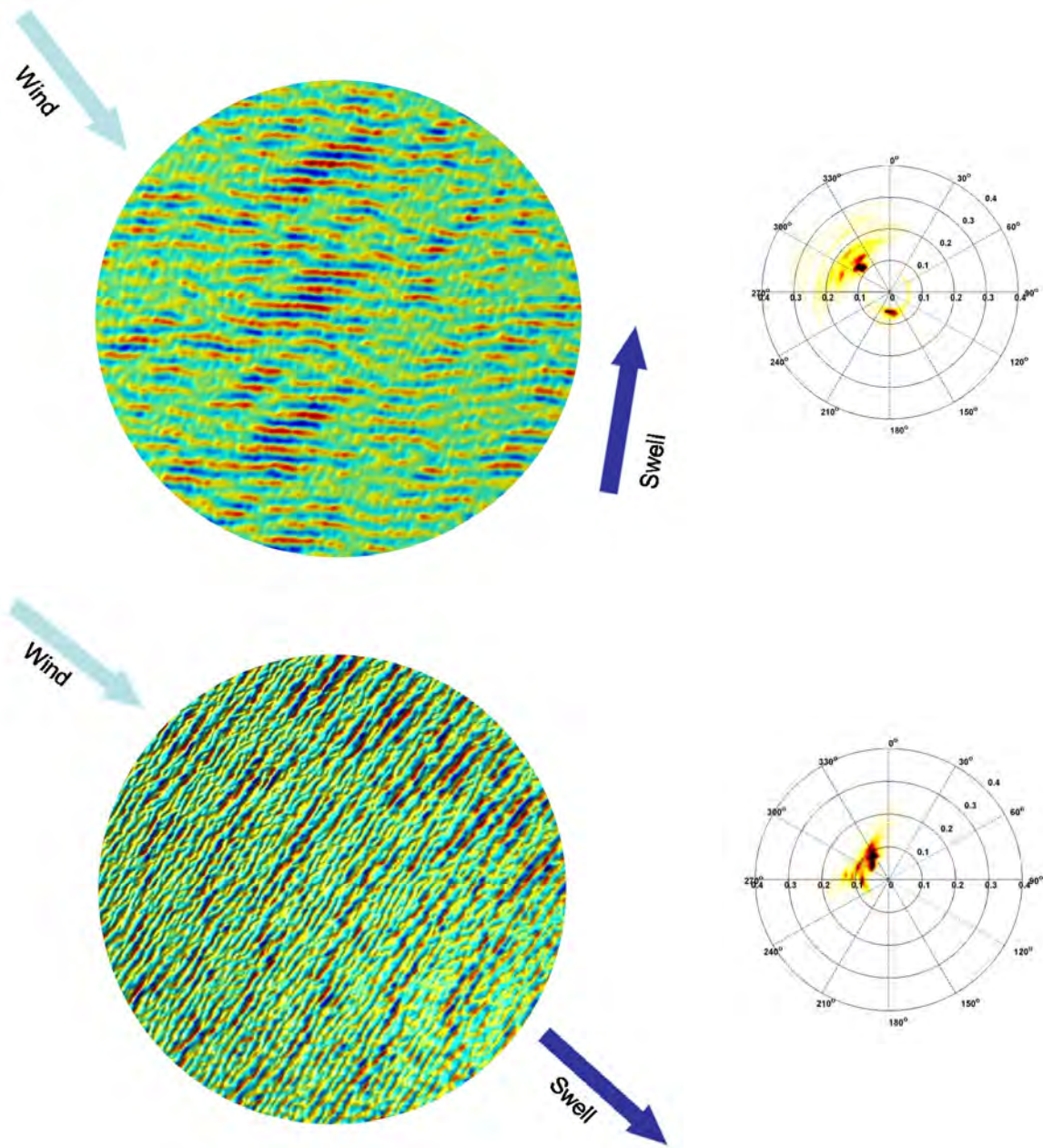


Figure 1. Simulation of sea surface based on buoy observations at Harvest Platform located in deep water off Point Conception, CA. Left panels: snapshot (diameter about 12 km) of simulated sea surface elevation. Right panels: corresponding observed frequency-directional wave spectra (source: CDIP). Upper panels: Typical summer-time South swell in the presence of a light North-West wind sea. Observations were taken in June 2006 (significant wave height 1 m, peak period 17 s). Lower panels: energetic North-West swells and sea in December 2006 (significant wave height 9 m, peak period 14 s).

The tentative experiment plan, described below uses 8 buoys spanning a distance of 10-20 km that includes several wave groups. These measurements, together with other in-situ instruments deployed by other investigators (i.e. ASIS buoys and sensors mounted on FLIP) and remote sensing observations (ship-board and airborne radars) will allow for a detailed investigation of nonlinear wave evolution over scales of a few wavelengths to several wave groups.

WORK COMPLETED

During FY07 we participated in the initial 1-year planning phase of the High Resolution Air-Sea Interaction DRI. During two meetings at the Scripps Institution of Oceanography a plan was developed for the main three-year phase of the DRI (FY08-FY10). The field experiments will be conducted in two stages: a pilot experiment in the spring of 2009 followed by the main experiment in the spring of 2010. Both experiments are tentatively planned to take place off Point Conception in about 500 m depth.

In the pilot experiment we tentatively plan to deploy one moored DWR buoy and four free-floating mini-DWR buoys. Other DRI participants will collect ship-board and airborne radar observations of the surface wave field, video observations of wave breaking events, and various atmospheric measurements.

The pilot experiment will span approximately a 10-day period to allow for acquisition of a data set with a range of conditions that will be useful for initializing numerical models. Our main goals are to try out different buoy deployment strategies to optimize their use in the main experiment, and test the precise synchronization in time and space with other experiment components to achieve a fully integrated data set. The pilot experiment will also provide us with a data set for preliminary analysis of nonlinear wave group evolution physics that will be used to improve the design of the main experiment.

In the main experiment, centered around the Scripps platform FLIP in about 500 m depth offshore off Point Conception, we plan to deploy an extensive array of DWR buoys spanning an area of about 10-20 km that contains the footprints of FLIP-based and shipboard radar systems (Figure 2). Within the FLIP radar footprint, we will deploy three moored, 0.7 m diameter DWR buoys to provide continuous in-situ wave observations during the experiment for validation of radar processing schemes in a wide range of conditions. In addition, we will deploy five 0.4 m diameter mini-DWR buoys during the intensive phases of the experiment, when ship-board radar measurements and aircraft over-flights take place, to enhance the spatial coverage of wave observations. The free-floating buoys will be deployed upwind of FLIP, then allowed to drift for several hours (while being monitored), and retrieved downwind off FLIP. Numerous ship-board buoy deployments will be conducted during the 5-week-long experiment in concert with other ship-board measurements and aircraft over-flights. Together, the 3 moored buoys and 5 free-floating buoys will form a dense coherent, two-dimensional array for observing wave group evolution over a distance of approximately 15 km. The deployment of the free-floating buoys can be adapted to the attendant weather (wind/swell) conditions, the configuration of ship-board and airborne radar systems, and data assimilation strategies employed in the numerical modeling efforts.

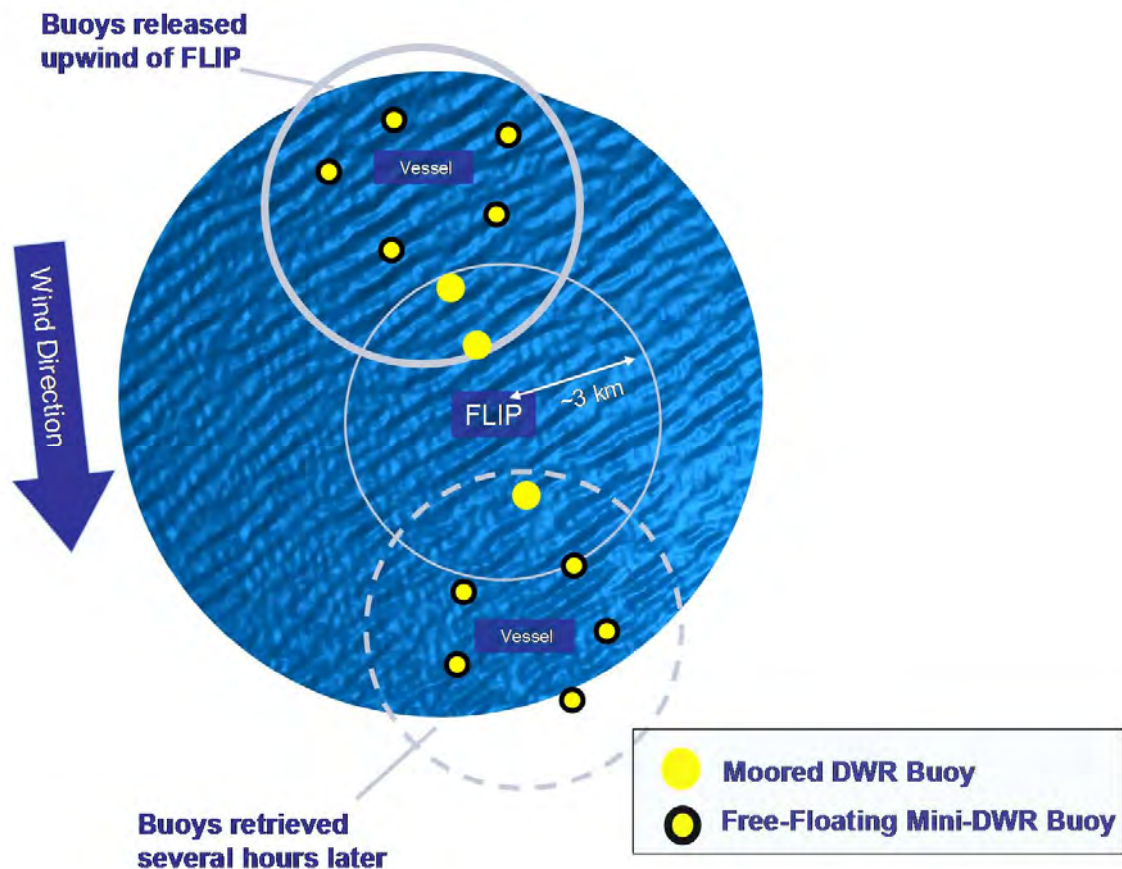


Figure 2. Sketch of a possible experiment configuration. Three moored directional waverider (DWR) buoys span the footprint of FLIP-based radar systems. Five free floating mini-DWR buoys will be deployed from a research vessel equipped with ship-board radar systems (footprint indicated in figure). The vessel will remain near the free-floating buoys and keep them in the radar footprint (dashed circles) as they drift downwind. After several hours the buoys will be retrieved and redeployed upwind of FLIP.

IMPACT/APPLICATIONS

This project will yield an improved understanding of ocean surface wave dynamics in deep water and a comprehensive verification of numerical models and radar remote sensing techniques in natural broadband sea states. These results are critical in the future development of a system for routine monitoring of the wave resolved sea surface around a vessel.

RELATED PROJECTS

We are investigating ocean wave dynamics in shallow water environments in the ONR Coastal Geosciences Projects: Wave-Mud Interactions and the Seafloor Ripples DRI. While the focus in these projects is on the interactions of ocean waves with the seafloor, the numerical modeling approaches and measurement techniques are similar. In addition to these synergies, the combined deep- and

shallow-water efforts will provide valuable insight in the role of finite-depth effects in nonlinear wave dynamics, and the associated wave group properties and extreme wave statistics.

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